G Model
IJLEO-55152; No. of Pages 4
ARTICLE IN PRESS
Optik xxx (2014) xxx–xxx
Contents lists available at ScienceDirect
Optik
journal homepage: www.elsevier.de/ijleo

Research on enhancement sensitivity of embedded fiber Bragg grating sensor

Luo Jun, Yaping Zhang, Wei Xu*

Kunming University of Science and Technology, Kunming 650000, China

ARTICLE INFO

Article history:
Received 17 December 2013
Accepted 20 July 2014
Available online xxx

Keywords:
FBG sensor
Sensitizing design
Elastic modulus
Strain transfer

ABSTRACT

With its unique advantages, embedded fiber Bragg grating (FBG) sensor is more and more used in the field of engineering structural health monitoring. According to the actual needs of engineering monitoring, we combined with the internal structure to make sensitivity design of the sensor. It mainly through setting the elastic modulus and the radius of sensor's inner sheath intermediate section, to make the strain of middle section larger than average strain, In order to achieve the increasing sensitivity. Through the analysis, the enhancement degree is relevant to the length, radius and elastic modulus of the middle section, so it could achieved different requirement of sensitizing by adjusting these parameters. Through the analysis of the core strain in the sensitizing structure, it can obtain the strain transfer distribution in the scope of sensor. All these could provide the theory basis for the realization of embedded FBG sensor's sensitivity enhancement.

1. Introduction

Packaging protective of fiber grating can solve the problem of durability in a certain extent. But when the sensor is in actual use, it often face the problem whether can fully feel the structure strain. Bare fiber grating in strain and stress sensitivity coefficient are respectively 0.003 nm/MPa [1] and 0.0012 nm/$\mu\varepsilon$, these sensitivity coefficient are low. In addition, the fiber Bragg grating precision is 1 $\mu\varepsilon$ [2], it is also not easy to meet the requirements of small strain but high precision monitoring. These are to some extent to put forward new requirements on the use of FBG strain sensor. Therefore, how to improve the sensitivity of the sensor on the outside strain became reality. The main purpose of this paper is in view of the sensor structure, putting forward the sensitizing solution. And the sensitivity coefficient and the strain of core is studied and discussed.

2. The sensitivity design of FBG sensor

Though fiber grating sensor has many advantages, but the pressure and strain sensitivity of bare FBG is low. It makes the actual detection inconvenience. In addition, the bare optical fiber is thin and the material is brittle and easily damaged, it needs to provide certain protection measure when used. The main measure to realize the protection is encapsulation. These packaging methods not only to protect the optical fiber, but also achieve the strain transfer sensitization to some extant [3].

For the research on sensitivity enhancement of fiber Bragg grating sensor. At present, the most part were sensitivity to temperature and pressure [4–6], while the enhancement sensitive of strain were rare. REN Liang et al. [7] who were in Dalian University of Technology had designed a two clamping strain sensitivity sensor. This sensor can increase the strain transfer by setting the sensor parameters. The test performance is superior to the bare fiber. It also can be used in the design of embedded and surface clamping sensors, this example has some inspire for this paper. Generally speaking, the sensitivity study on embedded FBG strain sensor is far from meet the practical application of this sensor.

To understand the basic structure of embedded sensor is the precondition of achieving the strain enhancement sensitivity design. The embedded sensor structure could show as below.

As shown in Fig. 1, the outer sheath is mainly served to isolate the internal structure out of tested materials as protection, so it could not play a direct role in enhancement sensitivity of the sensor. While the inner sheath was linked to the metal rings in the two ends. At the same time, through the middle layer ultimately drive the optical fiber core to product strain. So the inner sheath is the key structure which should be considered for enhancement sensitivity study. The sensor is mainly fixedly with the material to be measured though both ends of the metal rang. The metal ring in pace with measured structure makes the inner sheath to generate

* Corresponding author. Tel.: +86 871 65916780.
E-mail address: xuw02@mails.tsinghua.edu.cn (W. Xu).

http://dx.doi.org/10.1016/j.ijleo.2014.07.134

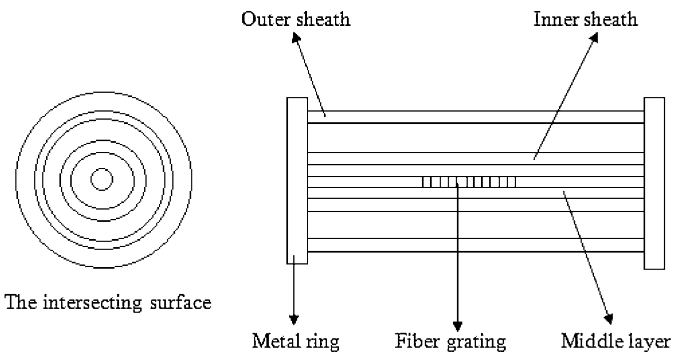

Fig. 1. The basic structure of embedded FBG sensor.

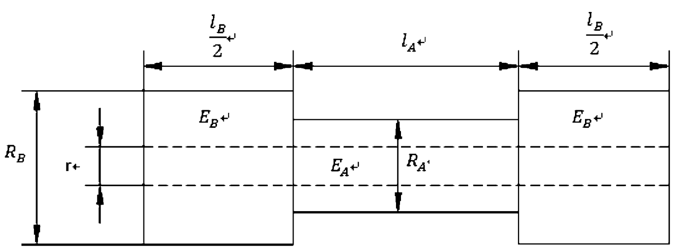

Fig. 2. The straight view of sheath in enhancement sensitivity structure.

corresponding strain. The total strain of the inner sheath (which would be called as sheath in the rear for simpler sign) was consistent with the total strain of the tested structure among the sensor length. Because of fiber grating was layout in the middle. So the section where really play a key role for train transfer was the middle of the sheath in the sensor. Thus, in the condition that the overall strain remains unchanged. Realizing the strain enhancement sensitivity of the corresponding region in the middle where laid fiber Bragg grating is the basic for enhancement sensitivity of sensor. Based on the nature of strain enhancement sensitivity, it can realize the purpose of strain enhancement sensitivity by enhancing the strain of the corresponding region where had laid fiber Bragg grating.

By increasing the elastic modulus and radius of middle sheath could realize enhancement of strain sensitivity. The enhancement sensitivity structure can be shown as below.

As Fig. 2 shown above, the sheath was setting smaller radius and smaller elastic modulus in the middle. The cross-sectional area of the two segment sheath was respectively as below (Fig. 3).

$$S_A = \pi(R_A^2 - r^2) \quad S_B = \pi(R_B^2 - r^2). \tag{1}$$

According to the force transmission theorem

$$\sigma_B S_B = \sigma_A S_A. \tag{2}$$

σ_A and σ_B represent the stress of the two segment materials. If the strain of two segment materials were respectively ε_A, ε_B, so

$$S_B \varepsilon_B E_B = S_A \varepsilon_A E_A. \tag{3}$$

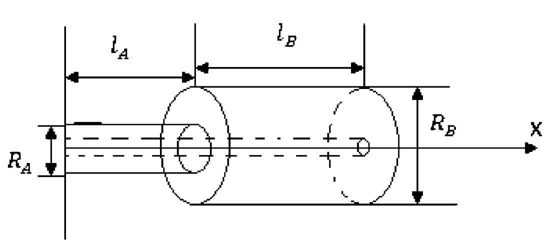

Fig. 3. Core strain analysis chart of sensitizing model.

Got the relationship between the two segment strain

$$\varepsilon_B = \frac{S_A E_A}{S_B E_B}\varepsilon_A. \tag{4}$$

While the average strain of the whole sheath was

$$\varepsilon \frac{\Delta l_A + \Delta l_B}{l_A + l_B} = \varepsilon_A \frac{l_A + \frac{S_A E_A}{S_B E_B} l_B}{l_A + l_B}. \tag{5}$$

Obtained the relationship between the middle section and average strain

$$\varepsilon_A = \frac{l_A + l_B}{l_A + \frac{S_A E_A}{S_B E_B} l_B}\varepsilon = k\varepsilon. \tag{6}$$

Because of $S_A E_A < S_B E_B$, therefore $k > 1$, it meant the middle section strain is greater than the average strain. k is enhancement sensitivity coefficient, according to the expression formula, when $\frac{S_A E_A}{S_B E_B}$ was smaller and $\frac{l_B}{l_A}$ was greater, the effect of enhancement sensitivity was more effective.

This sensitization method mainly adopts setting the radius, elastic modulus and length of sheath in different segments. It can adjust the parameters according to the different monitoring objects. And then meet the requirement of sensitization in different engineering monitoring.

3. The strain distribution of the fiber core of the sensitizing structure

The structure and sensitivity coefficient had certified the sensitizing design is feasible in theory. According to the principle of sensor, the measured strain came from the fiber Bragg grating in the core of middle segment. But the strain of core and sheath was not equal. There is strain transfer efficiency between them. Many scholars had studied the strain of core in non sensitizing sensor structure [8,9]. For sensitizing structure, the strain was not consistent among the sheath. So, the core strain analysis which studied before could not fully used in sensitizing structure. It needs to make detailed analysis and study on the core strain for sensitizing model.

Because the sensor is symmetric, it could only analyze half of it. According to the previous analysis, the character of sensitizing structure was increasing the strain of middle section while the whole strain remained unchanged. As the analyses in front, the strain of A, B sections were respectively ε_A and ε_B. The length were respectively l_A and l_B. The shear force between the core strain and intermediate bonding layer at the two section sheath connection area should be continuous. Making the core strain of joint was ε_Δ, and which should be determined. It would obtain the expression formula in the rear. The radius of core was r_c, the elastic modulus was E_c, the middle layer outer radius was r_a, the shear modulus was G_a. As the analysis in the front, the strain of A and B section were.

$$\varepsilon_A = \frac{l_A + l_B}{l_A + \frac{S_A E_A}{S_B E_B} l_B}\varepsilon. \tag{7}$$

$$\varepsilon_B = \frac{l_A + l_B}{\frac{S_B E_B}{S_A E_A} l_A + l_B}\varepsilon. \tag{8}$$

ε was the average strain of sensor, so the formula of core strain of the two sheath could be expressed as below [9]

$$\varepsilon_{cA}(x) = c_{1A}e^{kx} + c_{2A}e^{-kx} + \varepsilon_A. \tag{9}$$

$$\varepsilon_{cB}(x) = c_{1B}e^{kx} + c_{2B}e^{-kx} + \varepsilon_B. \tag{10}$$

k should express as below

$$k^2 = \frac{2G_a}{r_c^2 E_c \ln\left(r_a/r_c\right)}. \tag{11}$$